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THE OCCURRENCE OF ATMOSPHERIC THAW IN POLAND OVER THE LAST 50 YEARS

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Abstract

The study is concerned with the temporal and spatial characterisation of atmospheric thaw variability in Poland. The phenomenon was described on the basis of mean daily values of air temperature for the winter months October-March over the period 1960/61-2009/10 obtained from 34 meteorological stations of the Institute of Meteorology and Water Management (IMGW). It has been shown that atmospheric thaws occur on average as soon as 10 days after the first instance of a decrease in temperature below 0°C lasting at least 3 days. Atmospheric thaws are a constant element of the climate in Poland and occur with a frequency of 30-45% of the calendar winter (December-February) and 30% to almost 50% of the period of the thermic winter, that is the period between the date of the first decrease of mean daily air temperature below 0°C with a duration of at least three days and the date of its permanent increase above 0°C. Thaws are most common in the western part of Poland, particularly in the north-west, which, despite having the latest onset of the first thaws, is characterised by a high proportion of winter thaws of a length of 30 days and more. The spatial distribution of thaw is strongly dependent on longitude and less on height above sea level. Multiyear variability of thaw days is determined by atmospheric circulation. In the whole country (apart from the mountains) the correlation between the frequency of thaw occurrence in January, February, and March and the Jones NAO index is statistically significant at a significance level of α=0.01, and coefficients of determination fluctuate in general from 40 to 50% in January and February, and from 20 to 25% in March. The role of circulation expressed by NAO index in the explanation of the variability of thaw occurrence was statistically insignificant

Key words

atmospheric thaws • thaw periods ≥10, 20, 30 days • thaw-start and thaw-end date • temporal variability • spatial distribution • NAO index

Introduction

Atmospheric thaws occurring alternately with cool and frosty periods are characteristic features of the climate of Poland which is characterised by variability of weather conditions in the winter period. The meteorological dictionary (Niedźwiedź 2003) defines a thaw as the periodic, lasting several days, thawing of snow and ice on the ground surface after an increase in air temperature to over 0°C in winter, usually as a result of the advection of warm air. In foreign literature on the subject, the study of thaws is predominantly related to freeze-thaw cycles in polar and subpolar regions and the changes occurring as a consequence of global warming. The phenomenon of thaw is additionally mentioned in studies on the impact of global warming on the carbon dioxide exchange process and consequently on the course of biological processes (photosynthesis and evapotranspiration) in boreal and arctic vegetation (McDonald et al. 2004; Ho & Gough 2006; Zhang et al. 2011).

Studies on atmospheric thaw solely concern the phenomenon of atmospheric thaw in January. Godfrey et al. (2002) provided an overview of the most substantial results of studies on short-term warming of 3-7 days duration occurring in the third decade of January in selected cities of the NE part of the United States.

National literature on the subject includes few studies concerning thaw per se. First works on the classification of atmospheric thaw and meteorological causes of its occurrence in Poland were compiled by Kuziemski (1967, 1971). Many studies, including those by Mrugała (1987/1988a, b), Czarnecka (1990, 2009) and Czarnecka and Nidzgorska-Lencewicz (2010), have dealt with the characteristics of thaw on the scale of the whole country while other studies have dealt with it at the regional or local scale (Olszewski et al. 1997; Czarnecka 2005b; Olba-Zięty & Grabowski 2005; Czarnecka & Nidzgorska-Lencewicz 2006; Czarnecka et al. 2010).

Regardless of the criteria of thaw adopted and multi-year observation periods of different length analysed, the results of the aforementioned studies unequivocally confirm the fact that the western regions of Poland and the Polish coast are the most exposed to thaws. Mean temperature of most winter atmospheric thaws in the south-west of Poland does not exceed 3°C, whereas in the western regions the frequency of warming increases and the temperature exceeds 6°C (Czarnecka 2009). The greater intensity of thaw in the western part of the country is governed by long thaw periods, particularly of more than 20 days duration, during which temperature increases to over 4°C .

Atmospheric thaw is a phenomenon of significant importance for many areas of the economy. Depending on its intensity and duration, atmospheric thaw leads to the development of soil thaw and is a crucial factor resulting in non-enduring snow cover and the deterioration of its thermo insulating features (Bednorz 2009, 2011). Winter thaws contributing to the premature dehardening of winter cereals are consequently a significant factor for the wintering conditions of the winter cereals (Czarnecka 1998). Thaw has a negative effect on building durability and contributes to the deterioration of paving and rights-of-way. After each winter, the condition of paving deteriorates significantly from international standards and the cost of repair or repaving burdens the budget for road infrastructure. For example, the cost of repair of paving damage caused by temperature changes during winter in Canada constitutes 9% of expenditure on transport infrastructure (Ho & Gough 2006). Although winter thaws facilitate the increase in soil retention (Czarnecka 2005a), violent spring thaws, especially after a snowy winter, cause snowmelt floods which result in extensive damage to the economy and natural environment. Atmospheric thaws are important factors which participate in shaping bioclimatic conditions during the cool season of the year (Czarnecka & Michalska 2007). Both winter and spring thaws, regardless of their duration, contribute most to a decrease in thermal sensations referred to as 'cold' and an increase in the 'cool' category, yet result in only a slight increase in thermal sensations referred to as 'comfort'.

Most of the existing national studies on atmospheric thaws have relied on data from multi year periods of various length, usually concerning the last century. The principal aim of this study is the assessment of the temporal and spatial variability of atmospheric thaw on the basis of a relatively long measurement period of fifty years' duration, including the first decade of the 21st century, which enables an assessment of the trend of the phenomenon as represented by recorded and forecast climate change. An integral part of the study is the assessment of geographical and circulation determinants of thaw variability in Poland.

Data, area and methods

The literature on the subject lacks an unequivocal definition of and criteria for thaw. The quantitative characteristics of this phenomenon are based on mean daily or maximum, and even minimum, values of air temperature (Godfrey et al. 2002). In the national literature on the subject the first studies on atmospheric thaw were conducted by Kuziemski (1968, 1971) who suggested a maximum temperature be used as the indicator of thaw. Such a criterion of thaw was adopted by Mrugała (1987/1988a, b) and Olszewski et al. (1997). However, the lack of data concerning the maximum soil temperature in the archive of measurement sessions of IMGW makes it impossible to use an identical criterion in the assessment of soil thaw.

Therefore, in previous studies on the temporal and spatial variability of atmospheric and soil thaws (Koźmiński et al. 1990; Koźmiński & Michalska 2004) the author of the present paper adopted mean daily temperature as the criterion for the phenomenon. The results of the analysis conducted for the climatic and soil conditions in Stargard Szczeciński show that a statistical description of the occurrence of soil thaw at a soil depth of 10 cm, based on atmospheric thaw determined by the use of mean daily temperature, was comparable to the description based on atmospheric thaw determined by the use of maximum temperature (Czarnecka & Nidzgorska-Lencewicz 2006).

On the basis of Kuziemski's criterion of thaw (1967) the criterion adopted for thaw, like in previous studies on the topic, is that atmospheric thaw is constituted by periods with a positive mean daily temperature of at least two days duration occurring after the first period with a temperature below 0°C of at least three days duration. However, individual days with a temperature both above and below 0°C were disregarded. The distinction of the thaw periods as defined above into winter thaws (after which the return of thermic winter of at least two days duration is recorded) and the spring thaw (which ends the winter and leads to a permanent increase in temperature over 0°C) was taken into consideration. The duration of atmospheric thaw was expressed by the total number of days in which the phenomenon was recorded, and the duration of winter thaw was additionally expressed by continuous periods of at least 10, 20 and 30 days duration.

Mean daily values of air temperature recorded at 200 cm above ground level in 34 meteorological stations of IMGW from November to April in the period of 1960/61-2009/10 were adopted as the basis of the present study. Mountainous regions located over 600 m above sea level were excluded from the study – areas marked by hachuring on the maps.

Due to the fact that thaw occurrence is connected with the advection of warm air masses from the Atlantic Ocean, the present study includes an analysis of the influence of the North Atlantic Oscillation (NAO) on the frequency of thaw days during the calendar winter (December–February), and in its individual months. The indices formulated by Jones et al. (1997), available on the internet (www.cpc.ncep.noaa.gov), were adopted for this study. For the purpose of statistical evaluation of multiyear variability of this phenomenon as well as its circulatory determinants, linear regression analysis was employed. The results were presented by means of coefficients of determination R^2, expressed in %, significant at least at the level of α=0.05.

Results and discussion

In most of Poland the first period of at least three days duration in which the mean daily air temperature is below 0°C is recorded on average in the third decade of November (Fig. 1). The earliest thermic winter is registered in the eastern part of the Masurian Lake District (before 20th November) and the latest in north-west Poland (in the first decade of December). The first atmospheric thaw of at least two days duration occurs on average as soon as ten days later, that is in the first half of December. The dates of the thermic winter and the first atmospheric thaw point to differences of approximately three weeks. The dates of spring thaws which permanently end the thermic winter (Fig. 1) show slightly less spatial variability. On average, the spring thaw begins earliest, in the first decade of March, in the Silesian Lowlands and western part of Pomerania and begins latest, in the third decade of March, in the north-east of Poland.

The periods of atmospheric thaw occurrence are characterised by very high interannual variability. During the period of fifty years analysed, the extreme thaw-start and thaw-end dates differed by over three months (Fig. 2). In some years the thaw-start date was recorded as soon as in the first decade of November, but there were also cases when the first winter thaw occurred as late as January and sporadically in February. There were years in which the beginning of the spring thaw occurred as soon as in December, but there were also years in which the thaw began as late as in the first or second decade of April. In some regions of the country, for example Szczecin, there were cases of the first and last winter thaw as well as the beginning of the spring thaw being recorded in each month of the calendar winter (December-February), yet they were observed less frequently in December and more frequently in February. In most of the country such high variability of thermal conditions during the calendar winter was recorded only in January and February. The relative persistence of the thermic winter period within the area of Suwałki, the Polish 'pole

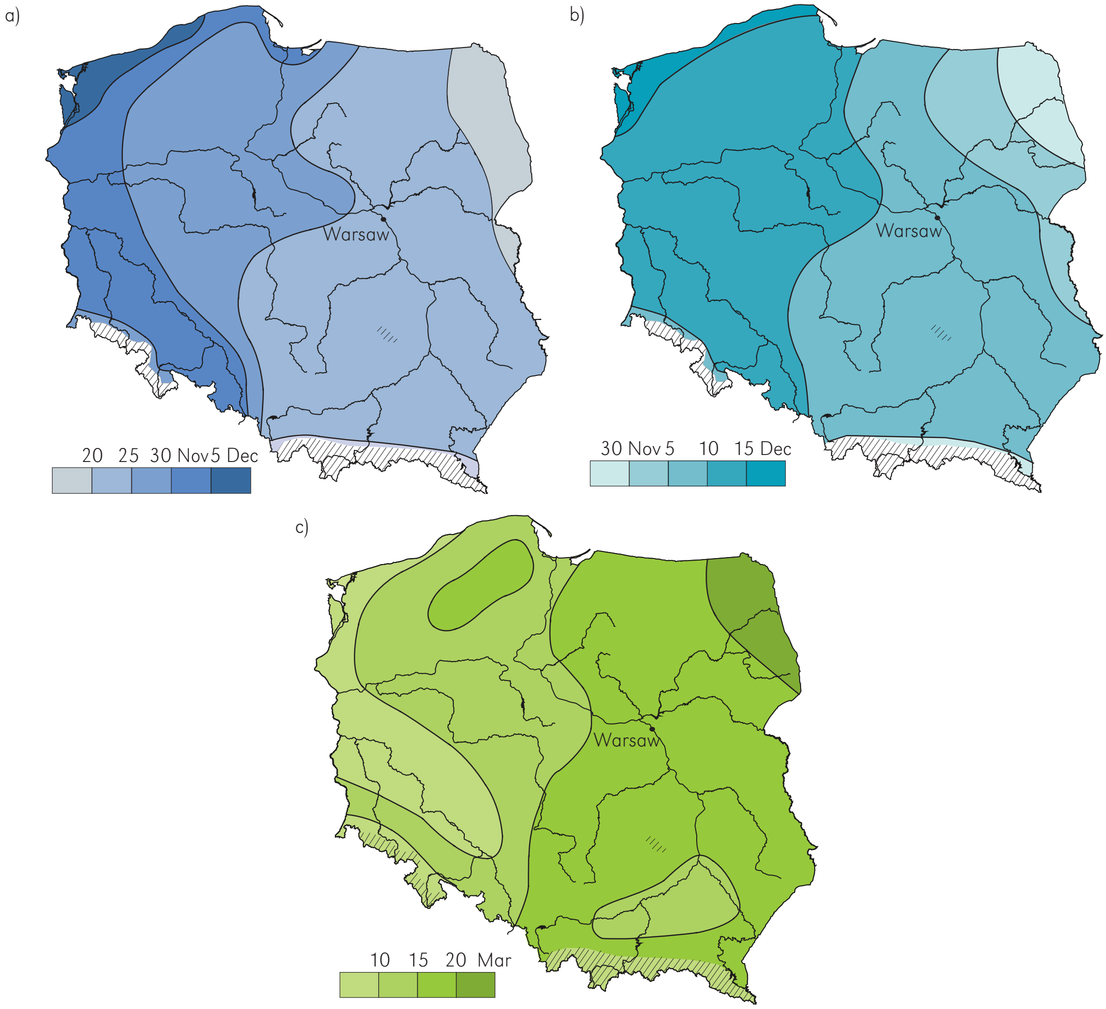

Figure 1. Mean dates of the beginning of: the first winter period (a), the first winter thaw (b), and spring thaw (c). Years: 1960/61-2009/10.

of cold', can be supported by the fact that in the period 1960/61-2009/10 in the second and third decade of January an atmospheric thaw was not recorded. Overall, on a national scale, the beginning of the winter thaw occurs most frequently (on average once every five years) in the third decade of November. However, for example in Suwałki, it is recorded with a frequency of approximately 30% as early as the second decade in November, whereas in Wrocław the frequency is similarly 30% but occurring in the first decade in December. In approximately 35% of cases the spring thaw begins in the third decade of March. The frequency with which the spring thaw begins in this decade shows great variability – from approximately 20% in Legnica to 50% in Suwałki. Though the thaw permanently ending the thermic winter is recorded most frequently in the third decade of March, in the second decade of the same month both the beginning of the spring thaw, and also the end of the last winter thaw, are recorded with comparable frequency.

In the period of the calendar winter (December-February), the mean number of days with atmospheric thaw increases from below 30 in the eastern parts of the Masurian Lake District and the Podlasian Lowlands to around 45 in the west of the country. Atmospheric thaw is recorded on over 30% of days each month (Fig. 3). In the Silesian Lowlands atmospheric thaw is even recorded on

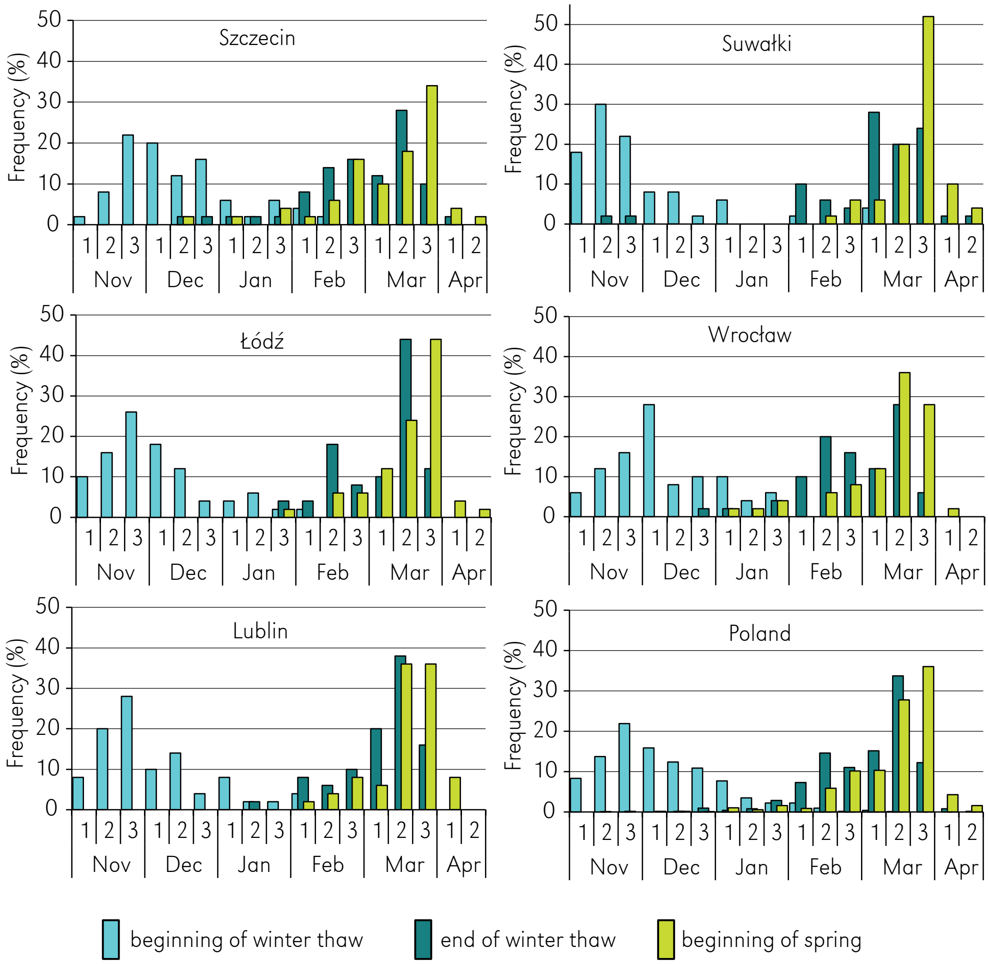

Figure 2. Frequency of occurrence (%) of the beginning of the first and the end of the last winter thaw and the beginning of the spring thaw. Years: 1960/61-2009/10.

half of the days in both of the coldest months of the year, January and February.

In most of the country, the frequency of atmospheric thaw is strong and gradually increases from the beginning of the first decade of November to the third decade of December (Fig. 4), which for example is illustrated by diagrams relating to selected stations as well as the diagram relating to the whole country developed on the basis of data from all 34 stations. In January thaws are most frequent in the third decade, and in February in the first decade. However, in February spring thaw accounts for a greater share of days with thaw than in January. These occur especially in the third decade in January and mostly in the western region of the country. The proportion of spring thaw permanently ending the period of the thermic winter begins to dominate almost all over the country from the second decade in March.

The potential duration of the winter period, as determined by the dates of the first and last period of at least three days duration with mean daily air temperature below 0°C, ranges from below 100 to almost 130 days (Fig. 5), and is approximately two weeks longer than the thermic winter period determined on the basis of mean monthly temperature (Koźmiński et al. 2001; Lorenc 2005; Czarnecka & Nidzgorska-Lencewicz 2010). The actual mean number of days in which the mean daily air temperature is below 0°C constitutes only 55-65% of the potential winter period which only emphasises the instability of thermal conditions in

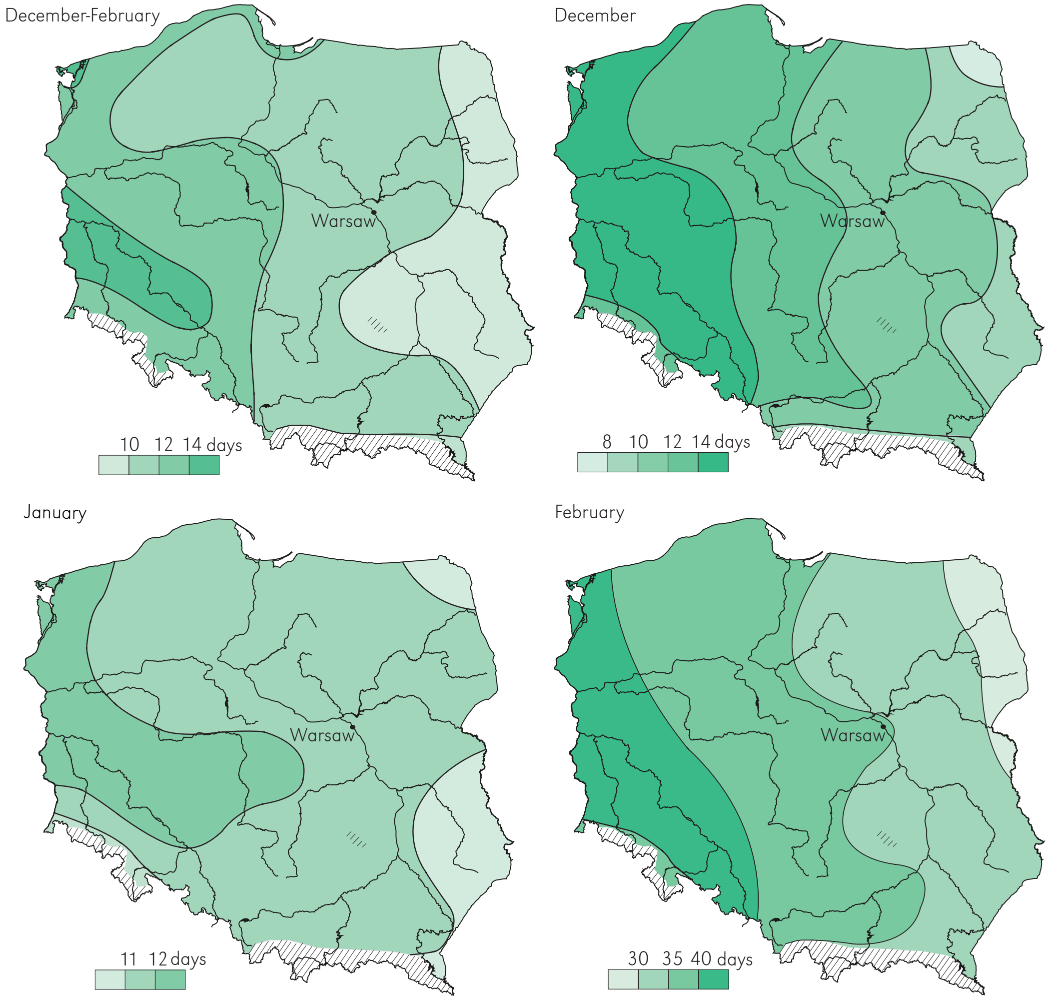

Figure 3. Mean number of days with atmospheric thaw. Years: 1960/61-2009/10.

this season of year. As can be seen in Figure 5, in the rest of the period, that is 35% in the north-east region of Poland and almost 50% in the west, winter thaws are recorded.

More than half of the cases of winter thaw occur in sequences of at least 10 days duration (Fig. 6), recorded in most of the country with a frequency of approximately 75% (Fig. 7). The share of winter thaws of at least 20 days duration in the total number of days with thaw, ranges from 25% in the east to over 45% in the west of the country, and sequences of such duration occur with 40 to 50% frequency – that is almost every second year. Sequences of 30 days duration and more are mostly recorded once every five years, and winter thaws occurring in most of the country in such long sequences constitute from 10 to 25% of all cases, and even 25% in the Szczecin Lowlands and coastal belt. The greatest contrasts in the occurrence of years with sequences of winter thaw of more than 10, 20 and 30 days duration are represented by the meteorological stations in Słubice and Suwałki (Fig. 7). In the area covered by the IMGW station in Słubice, winter thaws in sequences of at least 10 days are recorded with a frequency of more than 80%, and thaw periods lasting continuously for at least 20 or 30 days occur twice more frequently than in Suwałki.

The spatial and temporal distribution of atmospheric thaws, on the one hand, reflects the key directions with which the onset of thermic winter and early spring arrive, and, on the other, represents

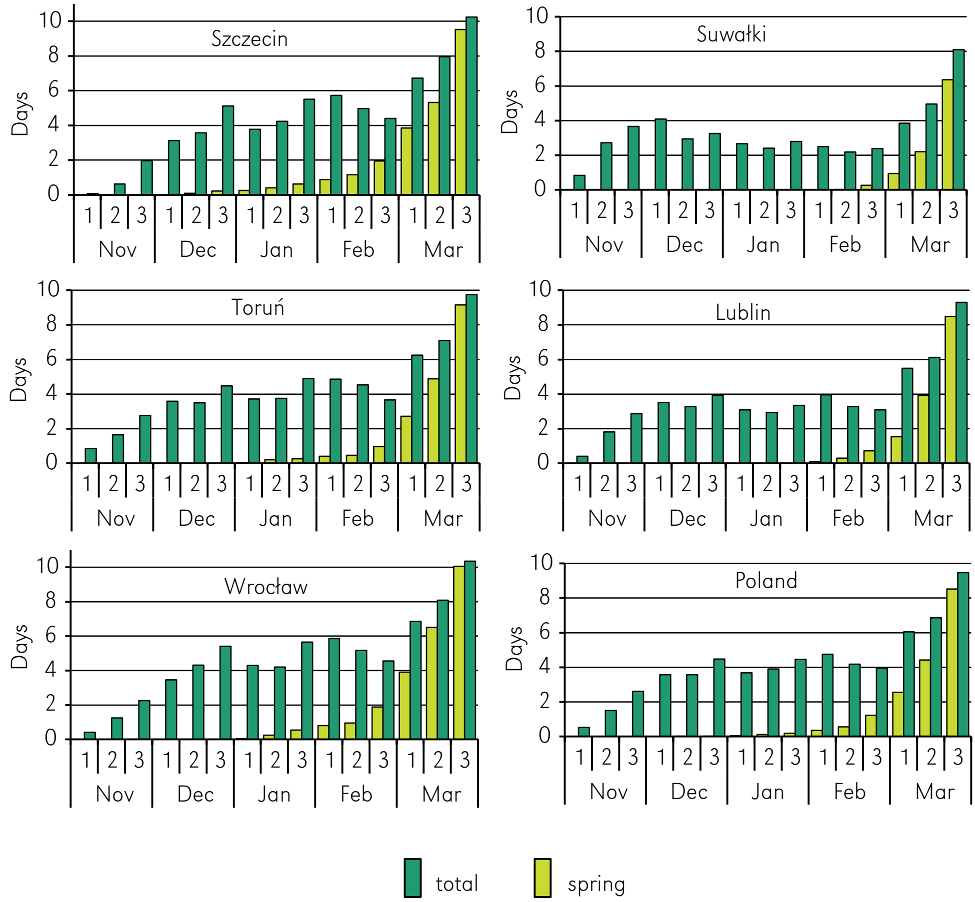

Figure 4. Decadal mean number of days with atmospheric thaw. Years: 1960/61-2009/10.

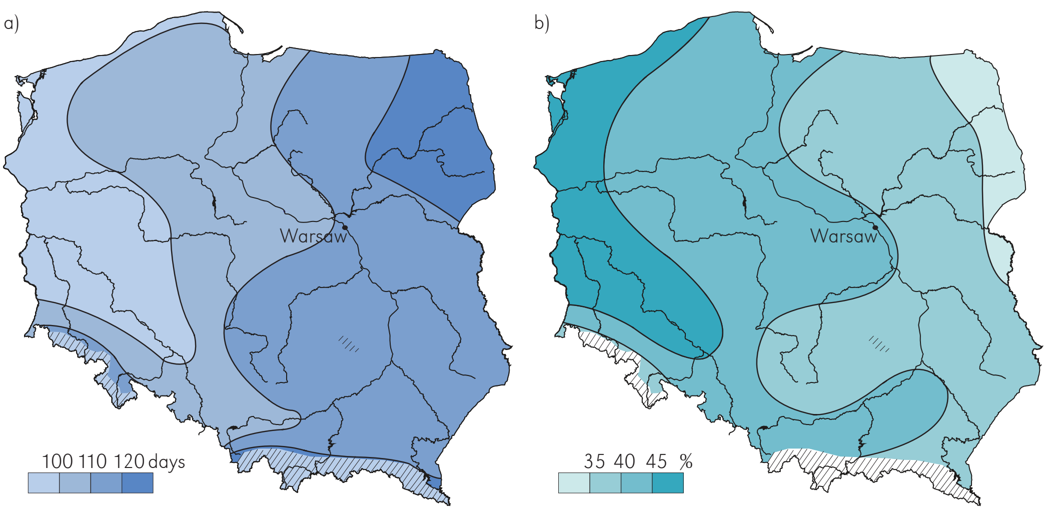

Figure 5. The number of days from the first and the last sequence of winter days (a) and the percentage share of days with winter thaw (b) during this period. Years: 1960/61-2009/10.

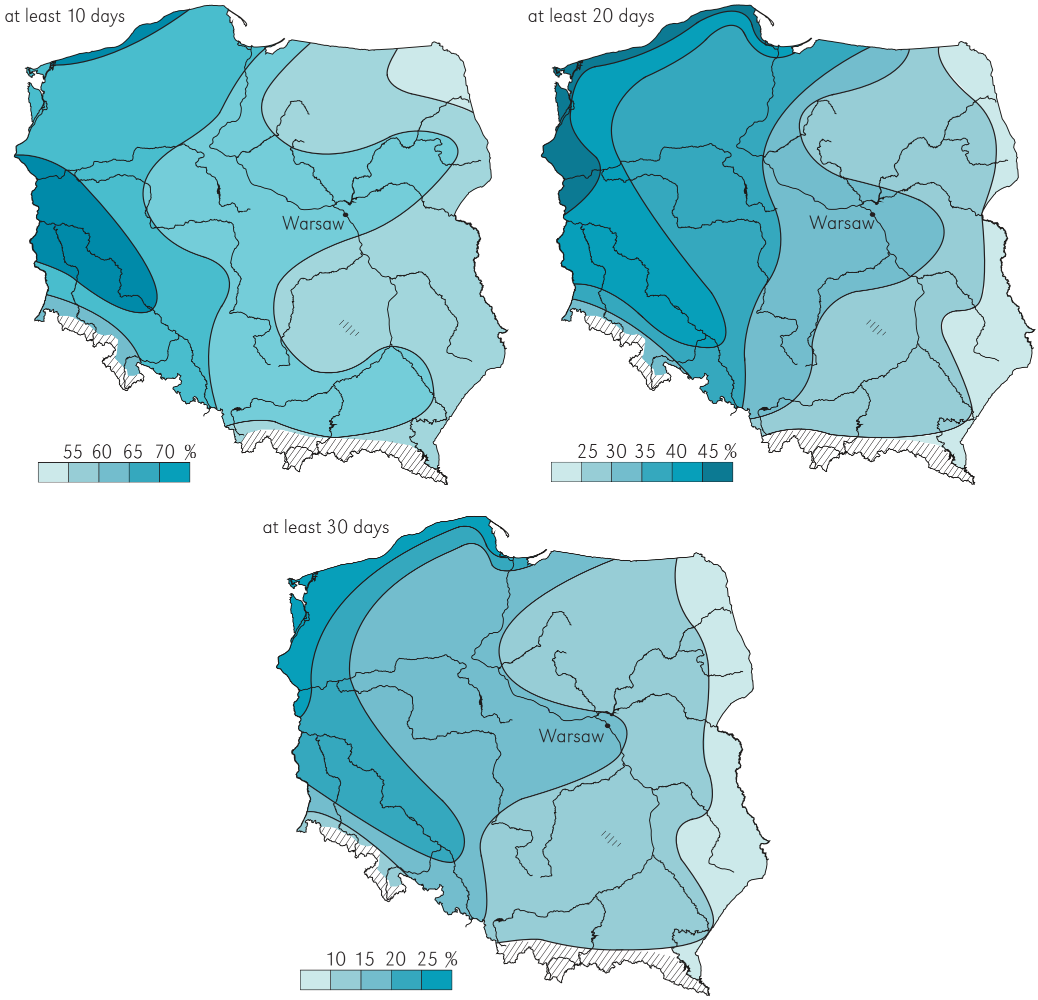

Figure 6. Percentage share of days with winter atmospheric thaw occurring in a sequence of at least 10, 20 and 30 days duration. Years: 1960/61-2009/10.

the characteristic trend to gradual harshening of weather conditions from the west to the east in the cold season of the year in Poland. Given the results of the studies conducted by Stopa-Boryczka and Boryczka on the determination of empirical relationships between the qualities of climate and geographical factors published in the study of several volumes entitled "Atlas of correlation of meteorological and geographical parameters" (i.a. Stopa-Boryczka & Boryczka 1974, 1976), and studies conducted by Mrugała (1987/1988a) directly concerning thaw, the correlations between the aforementioned features of atmospheric thaws, longitude and height above sea level were assessed. The results presented in Table 1 indicate the statistical importance of the effect of both geographical parameters on the spatial variability of dates and frequency of thaws. However, the effect of height above sea level proved to be several times less significant than that of longitude, which as a whole reflects those geographical factors responsible for the greater influence of continental features in Poland's transitional type of climate. These increase towards the east and in the main indicate a growing severity of thermal conditions in winter. From the standpoint of the accuracy of the relationship between those features, thaw and altitude, that were analysed, the fact that the stations representing areas located over 600 metres above sea level were eliminated from the analysis

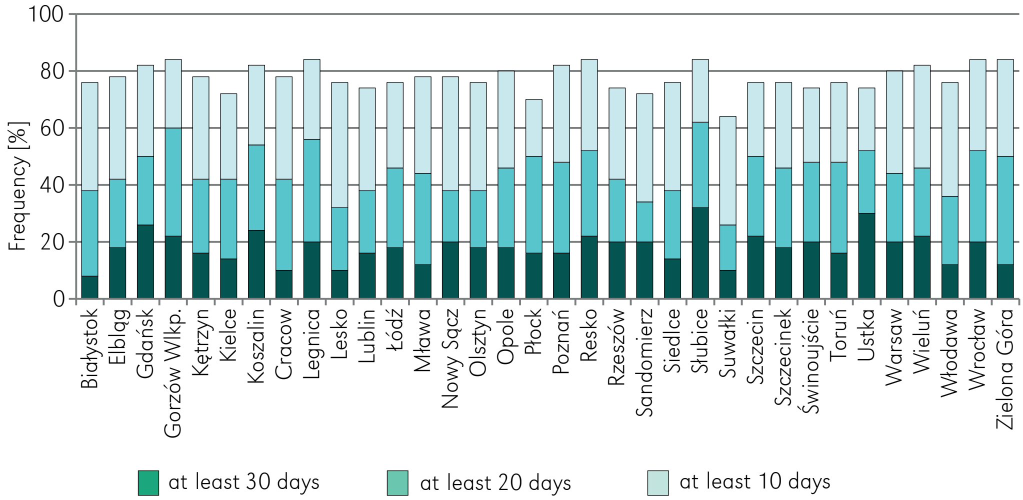

Figure 7. Frequency of occurrence (%) of winter thaw in a sequence of at least 10, 20 and 30 days duration. Years: 1960/61-2009/10.

proved to be important. Changes in longitude and altitude were the strongest determinants regarding the number of thaw days in January (coefficients of determination R^2 – around 81 and 35% respectively). The influence of these parameters was recorded at its weakest in December. The results obtained relating to the direction and importance of the relationship and its variation between the months of the calendar winter are congruent with the results by Mrugała (1987/1988a) regarding thaws, yet obtained with the use of a different criterion (maximum temperature) and a different multiyear period (1950/51-1979/80).

From the dates relating to the occurrence of thaws, the dates of the beginning of winter thaws bear the strongest relationship with longitude and height above sea level, and the dates of the end of winter thaws present the weakest relationship (Tab. 1). Moreover, longitude is a significant factor in determining the start dates of spring thaws. The gradients indicate an increase in thaw frequency in November with an increase in longitude and height above sea level which, above all, is connected with earlier onset of the first winter period. The increase in both parameters results in a later end date for the last winter thaw, and a delay in the beginning of spring thaw. The other characteristics of thaw indicate positive correlations with the aforementioned geographical parameters.

Atmospheric thaws are characterised by great interannual variability. In the period of 1960/61-2009/10, the average number of thaw days calculated for 34 stations for the period of the calendar winter (December-February), fluctuated wildly from below 10 to around 70 (Fig. 8). Atmospheric thaw was least frequently recorded in Poland in the years: 1962/63, 1969/70, 1978/79 and 1995/96, that is during the

Table 1. Coefficients of determination (R^2 in %) for the relationship between the number of days with atmospheric thaw and longitude and height above sea level. Years: 1960/61-2009/10.

Characteristics of thaws	Longitude	Height m a.s.l.
Days with thaw		
November	(+) 60.3	(+) 21.6
December	(–) 24.8	·
January	(–) 80.9	(–) 34.9
February	(–) 76.7	(–) 18.4*
March	(–) 67.4	(–) 14.7*
November-March	(–) 70.2	(–) 18.1*
December-February	(–) 77.9	(–) 23.7
Date		
beginning of winter thaw	(–) 71.5	(–) 41.5
end of winter thaw	(+) 37.9	(+) 24.5
beginning of spring thaw	(+) 56.8	(+) 19.7

· R^2 non significant at α=0.05; (–) / (+) dependence negative / positive
* significant at α=0.05, R^2 not marked with an asterisk: significant at α=0.01

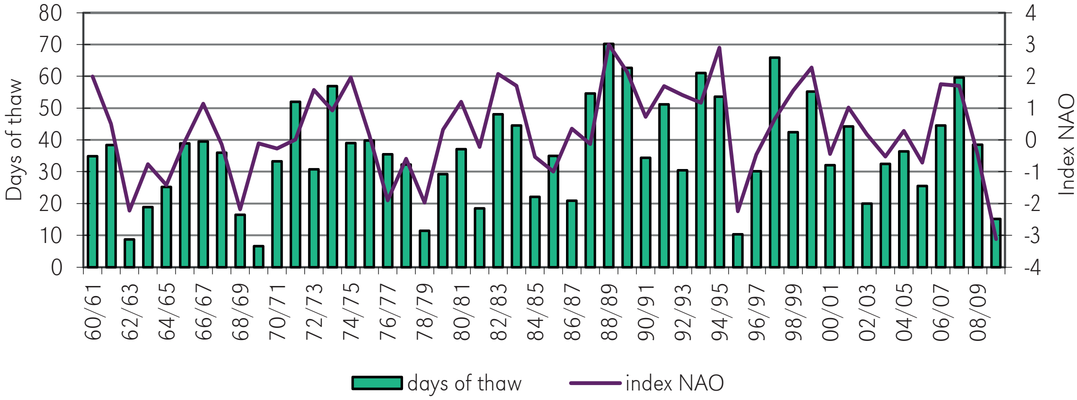

Figure 8. Variability of the number of days with atmospheric thaws and NAO index (Jones et al. 1997) during 1960/61-2009/10 in Poland.

warmest winters of this multi-year period (Lorenc 2005). In turn, thaws occurred frequently in the two subsequent winters: 1988/89 and 1989/90, and then in 1993/94 and 1997/98, and in the first decade of the 21st century – in 2007/08. In those years thaws were recorded on approximately 60 days, that is in 65% of the period of the calendar winter.

Contrary to the positive trend of air temperature during the winter period well-documented in the literature on the subject (Fortuniak et al. 2001; Kożuchowski & Żmudzka 2001; Boryczka & Stopa-Boryczka 2004; Degirmendžić et al. 2004; Żmudzka 2009), the assessment of the multiyear variability of days with thaw in general did not reveal a significant trend towards an increase or decrease in the frequency of thaws. This can be attributed to the fact that, according to the criterion adopted, the occurrence of thaw was determined by a previous period of winter of at least three days duration. However, contemporary warming is causing changes in the duration of the thermic seasons of the year. Though the dates of onset of the thermic winter, as determined on the basis of decadal or monthly values of temperature, do not show a clear tendency towards earlier or later occurrence, in many regions of the country a significant tendency towards shorter winters can be observed (Kossowska-Cezak 2005; Woś 2006; Nidzgorska-Lencewicz & Mąkosza 2008; Skowera & Kopeć 2008). Moreover, the increase in temperature occurred most of all in January and February and, according to the study by Kożuchowski and Żmudzka (2001) and Marsz (2005), December is marked by a clear cooling which is stronger in the eastern part of Poland than in the west. The insignificant trends in frequency of thaw occurrence almost certainly result from the linear trend adopted for the analysis. To a great extent the results depend on the values recorded in the first and last year of the multiyear period analysed. The few examples of the established positive linear trend at a statistical significance level of α= 0.05 concern almost entirely the number of days with winter thaw in January. Thaws occurring more frequently in January were registered in nine stations in the eastern part of Poland. In some of them (Kętrzyn, Mława, Olsztyn and Włodawa) the increase in the number of days with thaw, significant only at the level of α=0.10, yet close to the limit of the α=0.05 level, was evident also in December. This can be connected with the aforementioned decrease in temperature in December and in consequence with a slightly earlier beginning of the first winter period.

Interannual variability of thermal conditions on Polish territory is a consequence of changes in atmospheric circulation. An assessment of the influence of the types of circulation and kinds of air masses on the frequency of atmospheric thaw in Poland is included only in works by Kuziemski (1973) and Mrugała (1987/1988b), and in Pomerania – Chabior and Czarnecka (2008). Nevertheless, the strong relationship between air temperature and values of the NAO index, particularly in the winter months, has been proven in numerous studies (Marsz 1999; Marsz & Styszyńska 2001; Wibig & Głowicki 2002; Degirmendžić et al. 2004). Therefore it is valid to say that the changes in frequency of atmospheric thaws in the

Table 2. Coefficient of determination (R^2 in %) for the relationship between the number of days with atmospheric thaw and Jones's NAO index according to months from December to March. Years 1960/61-2009/10.

Stations	Longitude	Height m a.s.l.	R^2 in %				
			December	January	February	March	December-February
Białystok	23°11′	139	14.9*	45.9	45.7	25.2	45.7
Elbląg	19° 26′	38	·	31.4	43.3	22.1	34.8
Gdańsk	18° 36′	13	8.4*	37.4	42.7	18.7	46.0
Gorzów Wlkp.	15°15′	65	·	51.1	49.7	24.1	45.0
Kętrzyn	21°22′	108	21.4	53.8	46.3	19.7	52.9
Kielce	20°37′	268	24.1	49.9	40.2	26.4	43.7
Koszalin	16°10′	33	·	40.3	46.6	22.0	40.1
Cracow	19°58′	206	26.0	47.8	40.0	25.4	46.6
Legnica	16°10′	121	·	43.4	47.1	24.6	31.6
Lesko	22°20′	386	11.4*	23.2	23.4	23.3	21.9
Lublin	22°34′	171	18.1*	46.6	39.7	26.8	44.1
Łódź	19°24′	187	22.3	50.4	44.5	18.4	44.4
Mława	20°22′	141	22.7	50.2	44.0	26.3	48.6
Nowy Sącz	20°42′	292	15.0*	40.1	32.2	21.0	33.1
Olsztyn	20°25′	133	24.6	53.6	51.0	19.4	53.9
Opole	17°58′	176	·	41.2	42.5	23.6	37.8
Płock	19°40′	63	10.4*	52.4	44.2	20.1	45.5
Poznań	16°50′	86	·	47.9	44.9	24.5	38.7
Resko	15°25′	55	·	40.1	46.6	25.6	39.3
Rzeszów	22°03′	200	15.2*	40.5	31.9	25.0	33.3
Sandomierz	21°45′	202	13.1*	42.0	37.7	26.0	43.8
Siedlce	22°16′	146	19.5	49.6	44.8	23.5	51.1
Słubice	14°36′	21	·	42.1	46.9	21.3	31.4
Suwałki	22°57′	165	22.8	52.6	51.9	27.9	57.4
Szczecin	14°37′	1	·	36.8	48.6	23.1	34.6
Szczecinek	16°41′	137	·	48.7	46.0	25.8	41.2
Świnoujście	14°14′	6	·	35.9	44.3	24.9	34.6
Toruń	18°35′	69	10.5*	53.2	48.2	21.6	47.0
Ustka	16°52′	6	·	8.6	37.5	20.4	38.9
Warsaw	20°58′	98	14.5*	45.3	45.7	18.0*	44.7
Wieluń	18°35′	195	24.5	43.0	41.7	17.5*	44.9
Włodawa	23°33′	175	13.0*	38.0	46.4	26.3	43.4
Wrocław	16°53′	120	13.6*	53.6	46.0	23.2	46.3
Zielona Góra	15°30′	180	·	40.5	52.8	26.9	32.3

· R^2 non significant at α=0.05
* significant at α=0.05, R^2 not marked with an asterisk: significant at α=0.01

period of 1960/61-2009/10 are to a large extent synchronic with the course of Jones's NAO index. During the period of sixty years analysed, the periods of positive NAO phase were characterised by a greater number of days with thaw, and vice versa. The frequency of thaws was higher in winters in which the value of the index exceeded +2, that is in 1988/89 and 1997/98, respectively 70 and 66 days. A small number of days with thaw (about 10) was observed during seasons in which NAO index was -3 in the period from December to February, that is in 1962/63, 1969/70, 1978/79 and 1995/96. Table 2 presents the strong influence of atmospheric circulation on the occurrence of atmospheric thaw. The coefficients of determination describing the variability in the number of days on which atmospheric thaw occurs during the calendar winter (December-February) exceed 40% at most stations due to the circulation conditions and NAO index. In four stations, three out of which represent eastern regions of Poland (Kętrzyn, Olsztyn and Suwałki) the coefficients of determination exceed 50%. In most stations a stronger influence of circulation, reflected by NAO index, on the frequency of thaw occurrence was recorded in January and in some stations, usually located in the west of Poland, slightly higher coefficients of determination were noted in February. The smallest effect of NAO index was recorded in December. In stations located in the western region of Poland, coefficients of determination are statistically insignificant at a level of α=0.05. Weaker relationships between the frequency of thaws and Jones's NAO index in December can explain the results obtained by Marsz (2005) concerning the causes of the increasingly cool November and December in Poland. According to the author, in the period of 1971-2000, the increase in heat resources in the water mass of the NE part of the North Atlantic contributed to modifications in atmospheric circulation on a regional scale. As a consequence, this led to an increase in the frequency of air mass advection from higher latitudes thus disturbing the zonal, western circulation of air masses. In most of the country, except for the mountainous regions, atmospheric circulation, described by the NAO index, provides a significant explanation for the variability of thaws in March – mostly spring thaws ending the winter. However, coefficients of determination were around two times smaller than in January and February since in most stations they fluctuated from 20 to 25%. Yet, the statistically significant relationship between days with thaw in March and the NAO index, common across Poland, confirms Kuziemski's findings (1973) that few of the cases of spring thaws can be rated as strictly radiation (insulation) thaws – most belong to the advection-radiation type. The effect of circulation conditions on the frequency of thaw occurrence in the period of fifty years analysed (1960/61-2009/10) proved to be as strong as their intensity assessed in the period 1960/61-2004/05 (Czarnecka 2009). However, the analysis of the relationship between the dates of occurrence of atmospheric thaw both for winter as well summer thaws, and the NAO index, proved to be statistically insignificant at a level of α=0,05.

Conclusions

- Atmospheric thaws occur on average as early as 10 days after the first period of at least three days duration with temperature below 0°C, earliest in the north-east and latest in the north-west of Poland.
- The first winter thaw is usually recorded on average in the third decade of December, whereas the beginning of the spring thaw ending the winter is recorded on average in the second decade of March. The dates of the first and the last atmospheric thaws in Poland show a difference of approximately three weeks.
- Atmospheric thaws are common phenomena in Poland since they occur on around 30 to almost 45% of the calendar winter (December-February), and even in the coldest months, that is in January and February; half the days in the Silesian Lowlands are considered to be with thaw.
- The highest thaw frequency occurs in the western part of Poland, particularly its north-western region, which despite having the latest onset of first thaws is characterised by a high proportion of winter thaws occurring in sequences of 30 days duration and more.
- Spatial distribution of dates and frequency of occurrence of atmospheric thaw show statistically significant relationships between longitude and height above sea level; however the effect of the former is by far the greater.
- The dates of thaw occurrence do not show a significant trend towards delay or advance. More pronounced changes concern the number of days with thaw which in many regions of Poland is on the increase, especially in January.

– Frequency of occurrence of atmospheric thaw is determined by atmospheric circulation over the North Atlantic. The circulation conditions, expressed by Jones's NAO index, account for approximately 30 to 50% of the variability of thaw occurrence in winter in most of Poland, and their influence is as strong in January as it is in February.

Editors' note:
Unless otherwise stated, the sources of tables and figures are the author(s), on the basis of their own research.

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